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AN EXPERIMENTAL STUDY ON FLEXURAL BEHAVIOUR OF DAMAGED REINFORCED HPC BEAMS STRENGTHENED WITH CFRP WRAPPING

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ABSTRACT

Rapid development of Infrastructure is witnessed throughout the world. Many structures deteriorate or become unstable due to various reasons. Occurrence of natural calamities may also lead to one of the major problem. In many cases the past constructions reveal certain up gradations is necessary in three conditions: a) The structure is inadequately designed for the loading conditions. b) Structures that are found deficient under seismic conditions. c) The structure is damaged and requires rehabilitation. HPC has undergone many growths based on the persuade of cement type, type and proportions of mineral admixtures, type of superplasticizer and the mineralogical composition of coarse and fine aggregates. The constituent materials of HPC depend on the desired characteristics and the availability of suitable local economic alternatives. Cubes and cylinders were made with different percentage replacement of cement with fly ash and silica fume and strength tests such as cube compressive strength at 7th and 28th days and split tensile strength test at 28th days was performed. The test results showed that replacement of cement with combination of fly ash and silica fume the 7.5 % & 15% respectively gave better strength when compared to that of the normal conventional concrete. In this experimental study was carried out to study the flexural behavior of beams made out of high performance concrete. The beams were made from concrete having compressive strength of 60

Mpa. An experimental investigation was carried out to understand the structural behavior of reinforced HPC beams of size 2000mm (length) x 100mm (width) x 200mm (depth). The six beams were casted and tested under two points loading till their 70% load and it was strengthened by means of Carbon Fiber Reinforced Polymer (CFRP) sheets and that the strength of the distressed beam were examined. Maximum ultimate load carrying capacity and the least deflection is obtained for the mix prepared by partial replacement of cement with 7.5% silica fume & 15 % Fly ash.

Key words: SCC, M-sand, Clay roof tile, fresh concrete tests, hardened concrete tests.

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1. INTRODUCTION

It is an undeniable fact that concrete is the most widely used man- made construction material in the world today, and will remain so for the next few decades. The popularity of concrete is due to the abundance of raw material, excellence in strength and durability, low manufacturing and maintenance costs, versatility in forming various shapes and its unlimited structural applications in combination with steel reinforcement. However, the concrete industry faces a big challenge due to its vital component cement. The production of cement is an energy intensive process, and the emission of carbon dioxide during the cement production raises environmental concerns and there are increasing incidents where cement leads to distress in concrete in hostile environmental conditions. These factors have led to the thought of reduction of cement consumption and to intensification of research in exploring the possibility of enhancing strength and durability through the use of mineral admixtures.

Conventional concrete aggregate consists of fine and various sizes and shapes of gravel or stones. However, there is a growing interest in substituting alternative aggregate materials. Even though aggregate typically accounts for 70% to 80% of the concrete volume, it is commonly thought of as inert filler having little effect on the finished concrete properties. However, research has shown that aggregate in fact plays a substantial role in determining work-ability, strength, dimensional stability and durability of the concrete. The demand of natural sand is quite high in developing countries owing to rapid infrastructural growth. In order to avoid the pollution and reuse the waste material, the present study is carried out using M-sand and other eco-friendly materials.

1.2. High Performance Concrete

Concrete is the most widely used construction material in India with annual consumption exceeding 100 million cubic meters. It is well known that conventional concrete designated on the basis of compressive strength does not meet many functional requirements such as impermeability, resistance to frost, thermal cracking adequately. High performance concrete is a concrete mixture, which possess high durability and high strength when compared to conventional concrete. This concrete contains one or more of cementitious materials such as fly ash, Silica fume or ground granulated blast furnace slag and usually a super plasticizer.

1.3. Strengthening Using FRP

Only a few years ago the construction market started to use FRP for structural reinforcement generally in combination with other construction material such as wood, steel and concrete

which possess several improved properties such as high strength weight ratio. The use of FRP sheets or plates bonded on concrete beams has been studied by several researchers. Strengthening with adhesive bonded fiber reinforced polymer has been established as an effective method applicable to many types of concrete structures such as columns, beams, slabs, and walls. As the FRP material are non-corrosive, nonmagnetic and contains various type of chemical they are increasingly being used for external reinforcement of existing concrete structures. From the past studies conducted it has been shown that externally bonded carbon fiber reinforced polymer (CFRP) can be used to enhance the flexural ,shear and torsion capacity of R.C beams . Due to the flexible nature and ease of handling and applications, combined with high tensile strength –weight ratio and stiffness the flexible carbon fiber sheet are found to be highly effective for strengthening of R.C beams. The use of fiber reinforced polymer (FRP) for the rehabilitation of existing structures has grown very rapidly over the last few years .FRP can be used very efficiently in strengthening the concrete beams weak in flexure, shear and torsion. Unfortunately the current Indian concrete design standard (IS Codes) do not include any provision for the flexural shear and torsion strengthening of structural members with FRP materials .The lack of design standard leads to the formation of partnership between the research community and industry to investigate and to promote the use of FRP in the flexural, shear and torsion rehabilitation of existing structure .FRP is a composite material generally consisting of high strength carbon fiber

The laminates are stiff plates or shells that come pre-cured and are installed by bonding them to the concrete surface with a thermosetting resin. The shears are either dry or pre-impregnated with resin and cured after installation on to concrete surface. The installation technique is known as wet layup. FRP materials offer the engineer an outstanding combination of physical and mechanical properties, such as high tensile strength, light weight, high stiffness, high fatigue strength and excellent durability. The properties of FRP composites and their versatility have resulted in significantly saving construction costs and reduction time of facilities as compared to the conventional strengthening methods

2. EXPERIMENTAL INVESTIGATION

2.1. Materials

2.1.1. Cement

Ordinary Portland cement of 53 Grade was used and the specific gravity of cement was found to be 3.15. The physical and chemical properties of cement are presented in Table 1.

2.1.2. Fine Aggregate

Sand: Locally available natural sand with 4.75mm maximum size was used. Its physical properties are given in Table 2 and conformed to IS: 383 – 1970.

M-sand: Available in local market, 4.75mm maximum size. The physical properties are given in Table 2

2.1.3. Coarse Aggregate

Crushed stone: Locally available crushed stone with 12.5 maximum size and its physical properties are given in Table 3 and conformed to IS: 383 – 1970.

Clay roof tiles: This is collected from local clay roof tile building demolished to construct new concrete building. The physical properties are given in Table 3

2.1.4. Chemical Admixture

Super plasticizer Conplast SP430 complies with IS:9103:1999 and BS:5075 Part 3 and ASTM-C-494 Type 'F' as a high range water reducing admixture and Type G at high dosage is used.

2.1.5. Water

Water used was fresh, colorless, odorless and tasteless potable water free from organic matter of any type.

Table 1 Physical properties of cement

Physical Requirements	Requirement as per IS 12269 : 2013	Results
Fineness Specific Surface (m2/kg)	225(min)	280
Vicat Initial Setting Time (min)	30 (min)	45
Vicat Final Setting Time(min)	600 (max)	240
Soundness By LeChatelier Method (mm)	10 (max)	1
Soundness By Auto Clave (%)	0.8 (max)	0.074
Compressive Strength in 3 days (M Pa)	27 (min)	38
Compressive Strength in 7 days (M Pa)	37 (min)	48
Compressive Strength in 28 days (M Pa)	53 (min)	60
Normal Consistency	28%	29%
Specific gravity	3.15	3.15

Table 2 Physical properties of Fine aggregate

Physical tests	Sand	M-sand
Specific gravity	2.63	2.55
Fineness modulus	4.23	4.66
Bulk density kg/m^3	1540	1580

Table 3 Physical properties of Coarse aggregate

Physical tests	Coarse Aggregate
Specific gravity	3
Fineness modulus	5.04
Bulk densityg/m^3	1432

2.1.6. Fly Ash

Fly ash also known as flue-ash, is one of the residues generated in combustion and comprises the fine particles that rise with the flue gases. Ash that does not rise is termed bottom ash. In an industrial context, fly ash usually refers to ash reduced during combustion of coal. Depending upon the source and makeup of coal being burned, the components of fly ash vary considerably but all fly ash includes substantial amounts of Silicon dioxide [SiO_2] and calcium oxide [CaO], both being endemic ingredients in many coal-bearing rock strata. In the past, fly ash was generally released into the atmosphere, but pollution control equipment mandated in recent decades now requires that it be captured prior to release.Fly ash, which is largely made up of silicon dioxide and calcium oxide, can be used as a substitute for Portland cement. The chemical properties of fly ash are shown in the Table 3

Table 4 Chemical properties of fly ash

Chemical properties of fly ash	Composition %
SiO_2	59.00%
Al_2O_3	21.00%
Fe_2O_3	3.7%
CaO	6.9%
MgO	1.4%
K_2O	0.9%

2.1.7. Silica Fume

Silica fume is a by-product of producing silicon metal or ferrosilicon alloys. One of the most beneficial uses for silica fume is in concrete. Because of its chemical and physical properties, it is very reactive pozzolan and gives immediate strength. Concrete containing silica fume can have very high strength and can be very durable. Silica fumes consist primarily of amorphous [non crystalline] silicon dioxide. The individual particles are extremely small, approximately 1/100th the size of an average cement particle. The quality of silica fume is specified by ASTM C 1240 and AASHTO M 307.The chemical properties of silica fume are shown in the Table 4.5

Table 5 Chemical properties of silica fume

Chemical properties of silica fume	Composition %
SiO_2	93.6%
Al_2O_3	1.3%
Fe_2O_3	0.9%
CaO	0.5%
MgO	0.5%
K_2O	0.14%

2.1.8. Mix Proportions

Table 6 Description of mixes

MIX ID	CEMENT %	Silica fume % (a)	Fly ash % (b)	Fine Aggregates %	Super plasticizers, %
CNS	100	0	0	100	1
CMS	100	0	0	100	1
SF1	100- A	7.5	0	100	1
SF2	100 - A	10	0	100	1
SFF1	100 –A-B	7.5	15	100	1
SFF2	100–A-B	10	20	0	1

3. RESULTS AND DISCUSSIONS

In the present study, such properties of High performance concrete produced with fully replaced with M-sand were investigated based on hardened concrete tests, strengthening of damaged beams by CFRP wrapping and it is tested.

3.1. Flexural Behaviors of Unwrapped Beams

Figure 1 Reinforcement cage for flexural beam

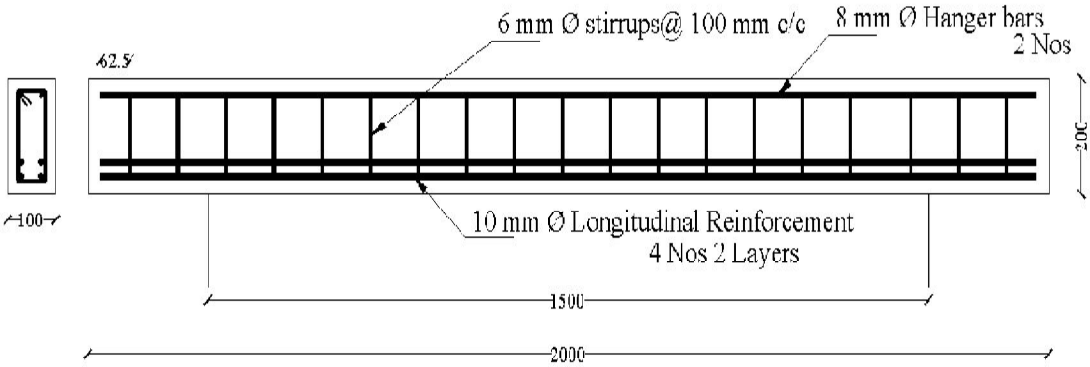

Figure 2 Reinforcement detailing of the beams

Figure 3 Test Setup of beams

The test specimens were tested in the loading frame of capacity 1000 kN. All the beam speciemns were subjected to two point loading and the loads were applied in the increments of 5 kN. The deflection values for each increment of loads were noted using LVDT.

The inclusion of admixtures in the beams resulted in higher ultimate loads as compared to the corresponding conventional beams. Greater deflection was observed under loads in beams cast with admixtures than the control specimen. In the case of beams cast with admixtures such as SF and FA, the failure was due to yielding of deformed steel and spalling of concrete on the compression side.

The beam specimen SFB2had the ultimate load carrying capacity of 69 kN in flexure. This is 46.8%higher than the load carrying capacity of CNSB which carried a load of 46kN. It was observed that the beams cast with SF, SF with FA showed higher load carrying capacities

compared to control beam. The increase in ultimate load carrying capacity for other beams when compared to the control beam was34.04%, 46.8%, 40.42% and 36.17% for SFB1, SFB2, SFFB1, SFFB2, respectively compared with CNSB. The initial crack load values increased when compared to that of control beam. From this, it is obvious that the addition of SF and FA increased the flexural strength of the beams because it delays the first crack. The increase in ultimate load carrying capacity for other beams when compared tothe control beam was 44.68%, 48.9%,42.55%,and 76.59 % for SFB1, SFB2, SFFB1, SFFB2 and CMSB respectively compared with CNSB.

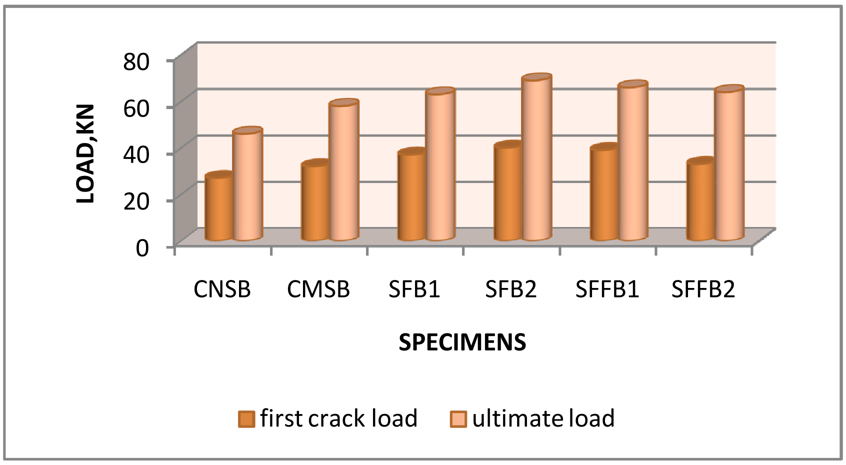

Figure 4

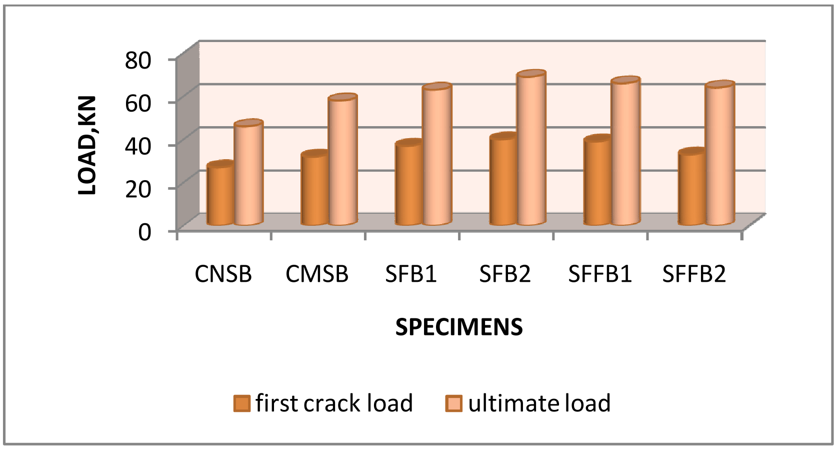

Figure 5

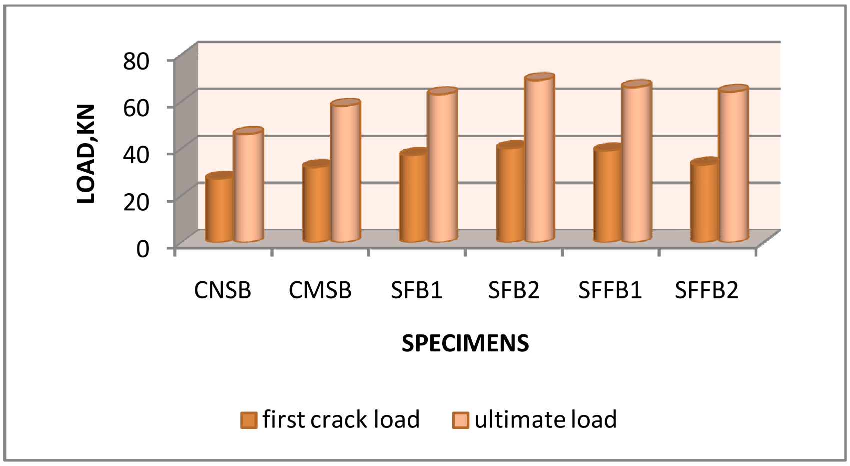

Figure 6

3.2. Flexural Behavior of Wrapped Beams

The beams were subjected to their first yield load and were wrapped with CFRP strips after straightening and filling the cracks. The testing was carried out on the rehabilitated beam to study their behaviour in flexure as stated in previous chapter. The beams were subjected to their first yield load and were wrapped with CFRP strips after straightening and filling the cracks. all beams retrofitted with two layers of CFRP failed in pure flexure.

The flexural failures observed were generally characterized by a single flexural crack occurring in the middle third of the beam extending upwards to the concrete top fibre between the load points and downwards through the retrofit material. All beams failed at loads higher than the average failure load of control beams. Moreover, both the deflection behaviour and failure modes were similar for all exposure conditions. The first crack appeared in the middle third of the tension strip. As the load was increased, the cracks propagated vertically in the side strips and the mouth of the initial crack in the tension strip opened gradually. As the load was increased further the propagation of the cracks on both sides of the beam towards the compression top fibre became visible. After the peak load, the load–deflection curves descended gently. Finally, the beam exhibited plastic behaviour with the yielding of steel. The comparison of load vs deflection curves SF and FA based beam specimens is shown in Figure P-delta curve.

From the P-delta curve, it was observed that the load-deflection curves are almost have the same slope upto 40 kN for all beams. Even though the CFRP and RC beam combination is a composite action, the most of the load was carried by the CFRP alone. After the failure of CFRP, the ultimate load was reached. In some beams the load carrying capacity enhanced when compared with unwrapped beams. In some beams load carrying capacity had been reduced. The failure of these beams was mostly by tearing of fibres. In silica fume based mixes, the highest ultimate load value was obtained for WSFB2 specimen which was about 97 kN , the all other test specimen greater than the WCNSB which carried a load of 74 kN only. The test specimen WSFB2 performed well in flexural behaviour and carried more load than all the other beams such as WSFB1, and WSFB3.

Increased values of deflection were observed for all the CFRP strengthened specimens and the one WSFB2 underwent maximum value of deflection which is equal to 35.6 mm and 65.04 % higher than the WCNSB. The deflection values exhibited an increase with the increase in the load. In comparison to the control beam, as the stiffness of the beams strengthened with CFRP increased, so did the cracking load of the beams increase. It was seen that the failure mode of the CFRP strengthened beams was not debonding, but CFRP rupture. However, the cracking and yield loads of the CFRP strengthened beams were greater than those of the unstrengthened, as a result of the increased stiffness due to the composite bonding. All the P-delta curves of the CFRP strengthened beams exhibited bilinear behaviour and indicated improved seismic behaviour. The behaviour of strengthened beams was stiffer than the beams tested without CFRP wraps. The external wrapping of CFRP layers to the HPC beams was found to enhance both the cracking and ultimate flexural strength of the beams.

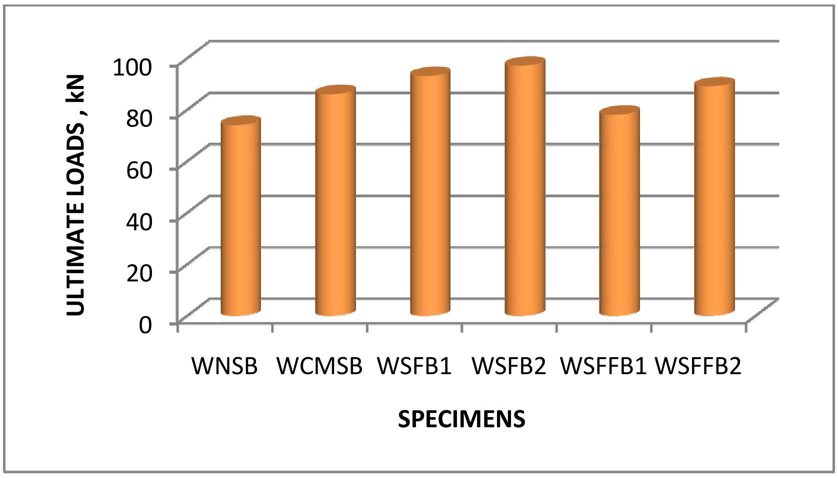

Figure 7 Comparison of ultimate loads for the CFRP wrapped beams

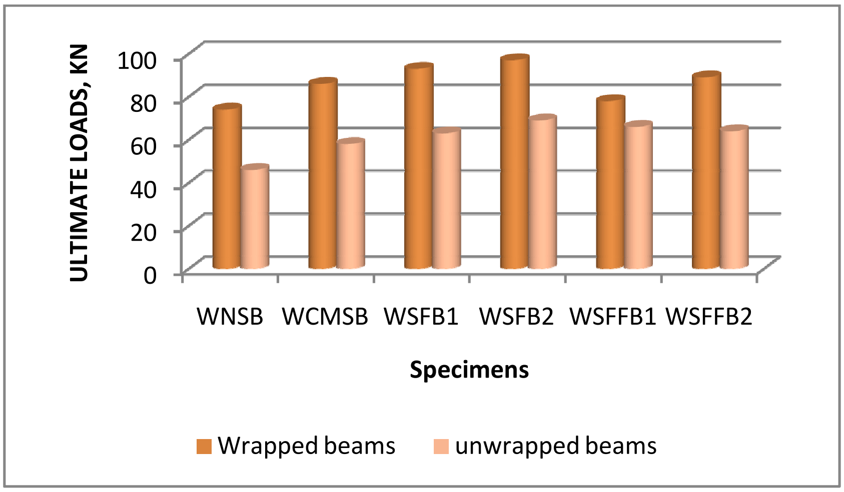

Figure 8 Comparison of ultimate loads for the unwrapped and CFRP wrapped beams

4. CONCLUSION

Based on the systematic and detailed experimental study conducted on HPC mixes with an aim to develop performance mixes, the following are the conclusions arrived.

- From the experimental test results, it is concluded that the beam cast with w/b ratio of 0.31 and denoted SFB2 exhibited higher ultimate loads in all cases.
- The beams cast with admixtures showed an appreciable increase in the load carrying capacity at the w/b ratios due to the denser matrix formed because of the presence of admixtures like SF and FA.
- All the beams showed an increased value of deflection due to the ductile behavior caused by the admixtures.
- The ductility of those beams with admixtures increased, when compared to the control beam.
- It is evident from this study that reinforced concrete beams made with silica fume and fly ash as cement replacement material can improve structural performance.

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